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# Modeling the Inner Magnetosphere

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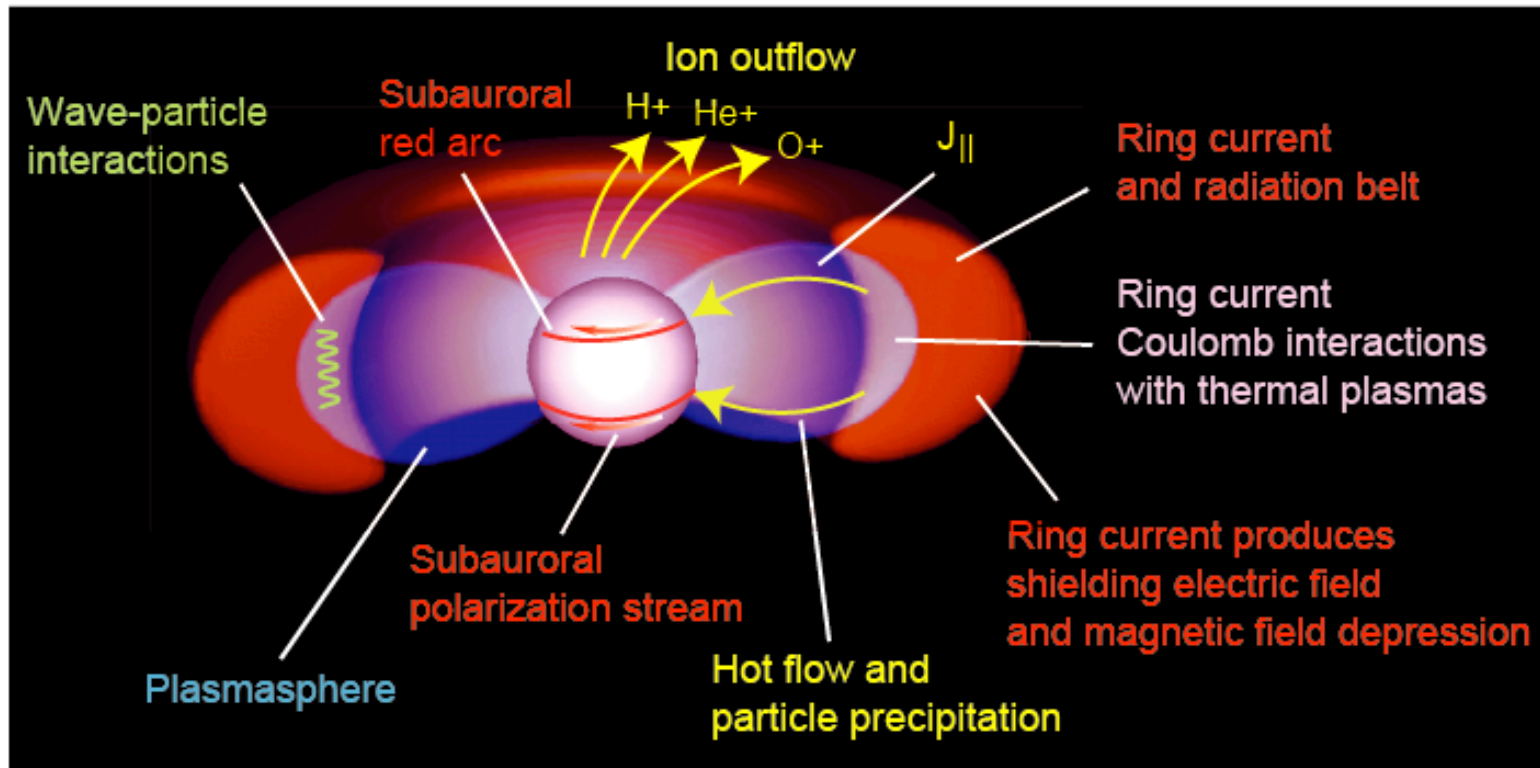
CAWSES International Workshop on Space Weather Modeling  
14-17 November 2006  
Yokohama, Japan

# Outline

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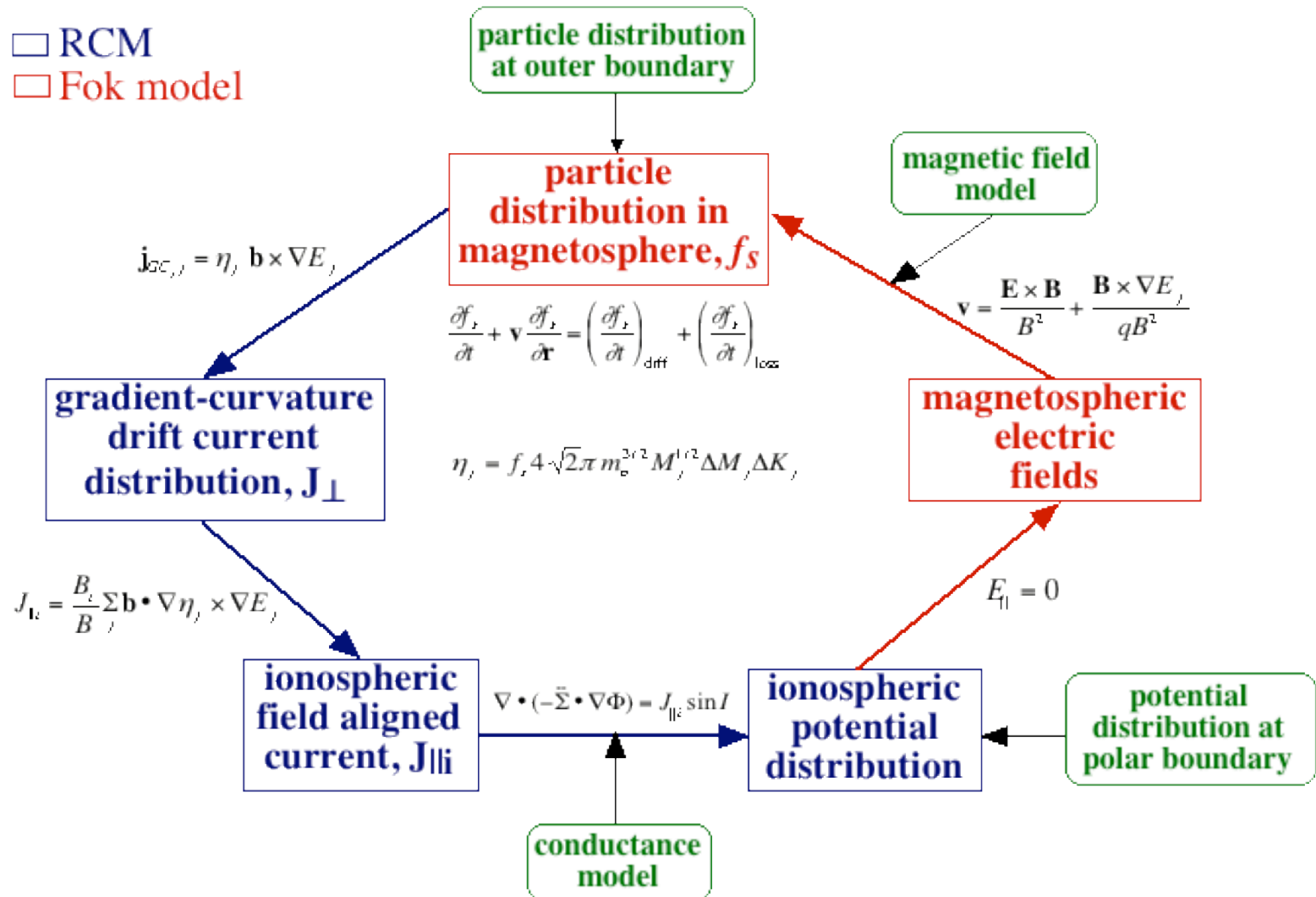
- ❖ Major interactions between plasmas in the inner magnetosphere
- ❖ Recent progress in modeling the inner magnetosphere
  - Ring current models with self-consistent E field (RCM, CRCM)
  - Ring current models with self-consistent B field (Zaharia-Jordanov, Wang-Chen)
  - Ring current models with self-consistent B and E fields (RCM-E, RCM coupled with Batsrus, LFM, OpenGGCM, CRCM coupled with OpenGGCM)
  - Radiation belt models with test-particle approach (Hudson, Li, Ukhorskiy)
  - Radiation belt models with kinetic approach (Salammba, Radiation Belt Environment (RBE) model)
- ❖ Model a substorm injection using LFM-Delcourt-CRCM
- ❖ Model the radiation belt enhancements during storms on 10-14 August 2000
- ❖ Real-time running of the RBE model at NASA Goddard
- ❖ Future works and challenges

## Major Interactions in the Inner Magnetosphere-Ionosphere



## Recent Progress: Ring Current Model with Self-Consistent E Field

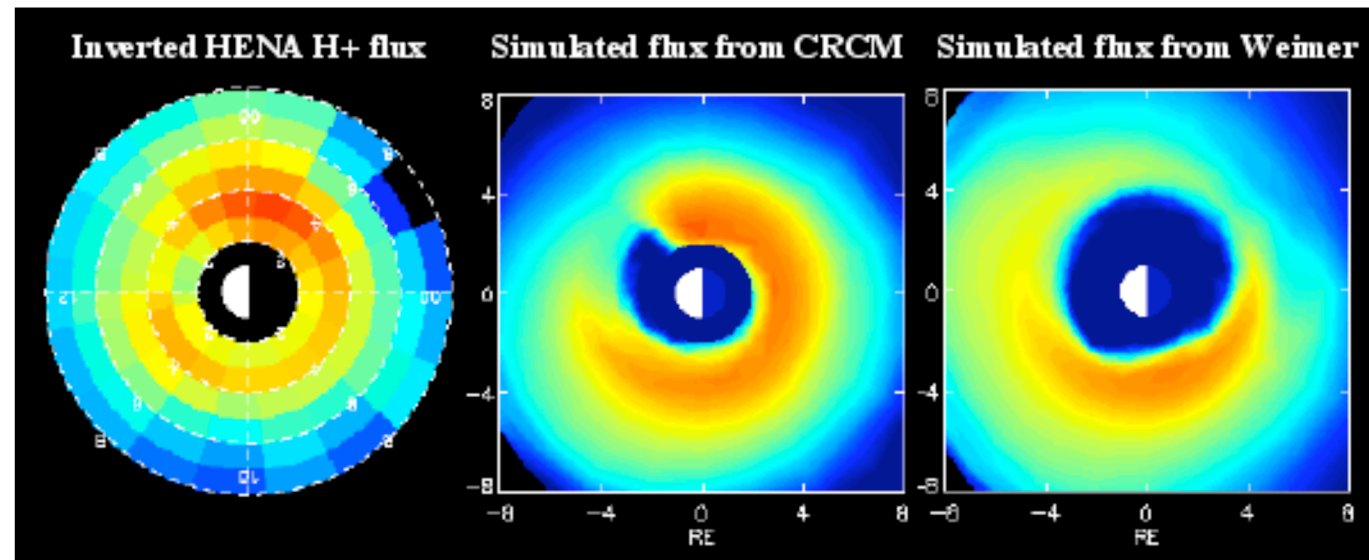
### The Comprehensive Ring Current Model (CRCM)





## CRCM Reproduces Post-Midnight Enhancement of Storm-Time Ring Current

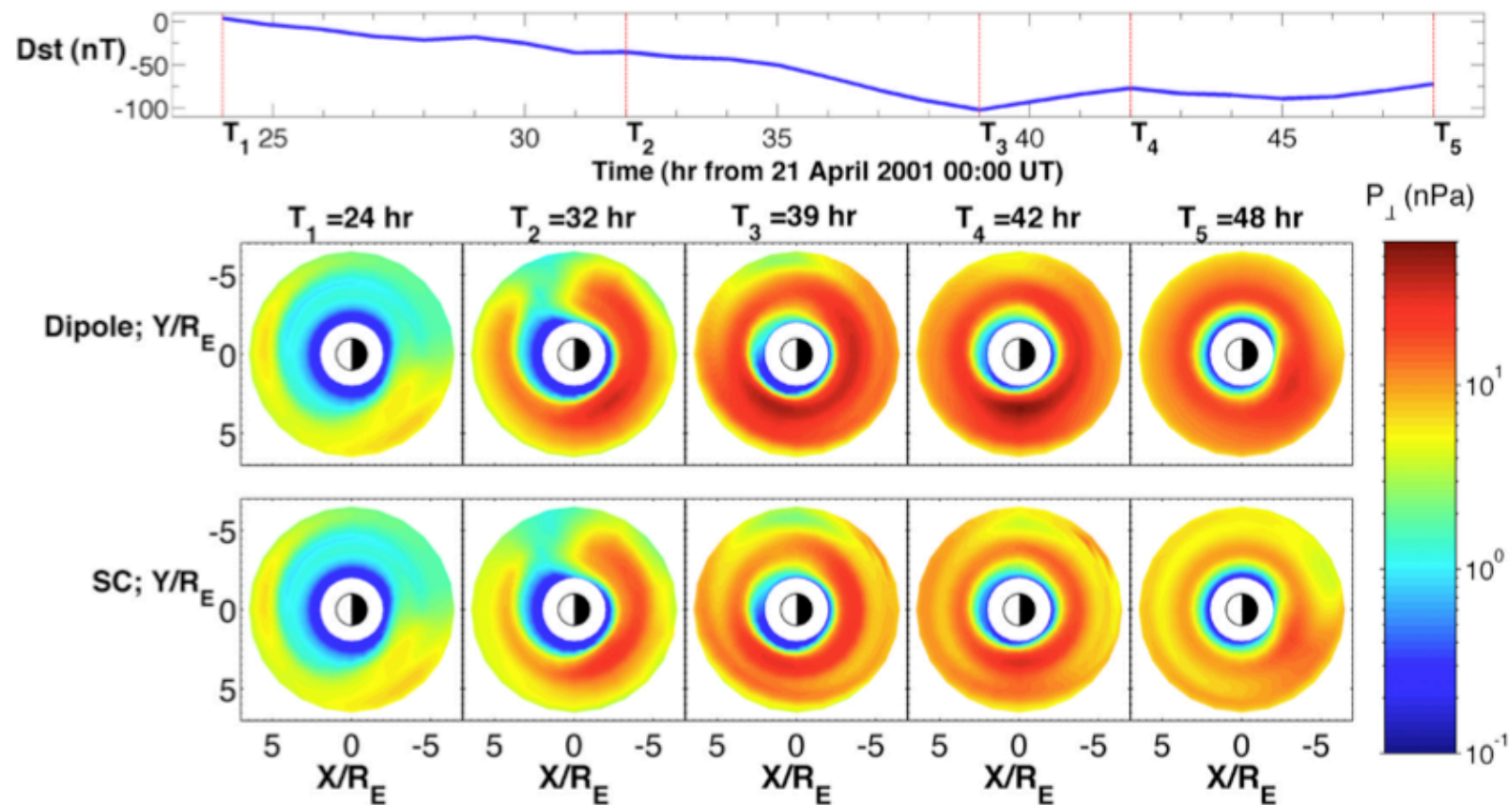
IMAGE/HENA  
9:40 UT  
12 Aug. 2000  
32 keV H<sup>+</sup>



- Post-midnight enhancement seems to contradict with the convectional wisdom and is not supported by many particle-drift calculations and ground-based measurements.
- CRCM simulations reveal that post-midnight peak is a combined effect of strong shielding field generated by the ring current ions and irregularities in the ionosphere conductance.

## Recent Progress: Ring Current Model with Self-Consistent B Field

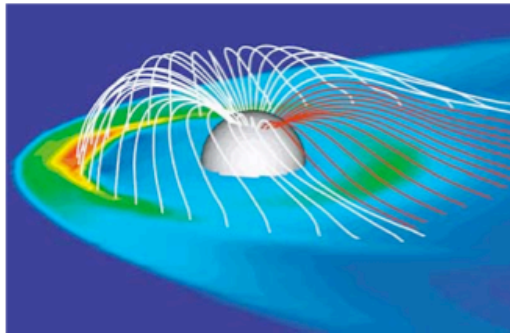
Kinetic Ring Current Model (RAM) + Force Balance Model (Zaharia and Jordanova)



Taken from Zaharia et al., 2006

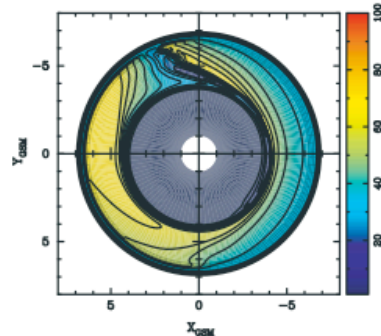
## Recent Progress: Ring Current Model with Self-Consistent B and E Fields

Global Magnetosphere-Ionosphere Model (MHD)



$\rho, \mathbf{u}, \mathbf{B}, p$  at cell centers  
Ionospheric potential  
 $\Phi$  distribution

Inner Magnetosphere Model (RCM)



Total particle pressure

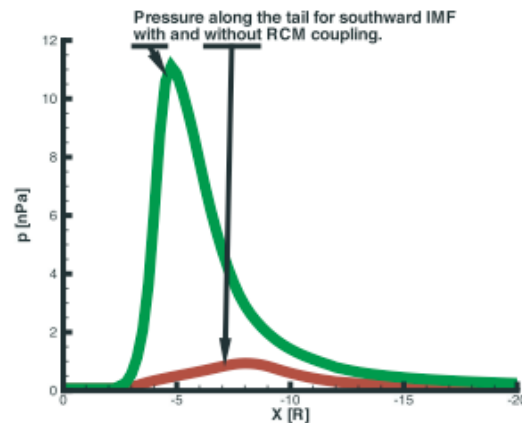
Map RCM superthermal pressure to magnetosphere grid (assuming that pressure is constant along magnetic field lines)

Calculate fieldline volume, fieldline mass, fieldline pressure, and equatorial plane temperature

Calculate equatorial crossing of magnetic field lines originating from RCM ionospheric grid points

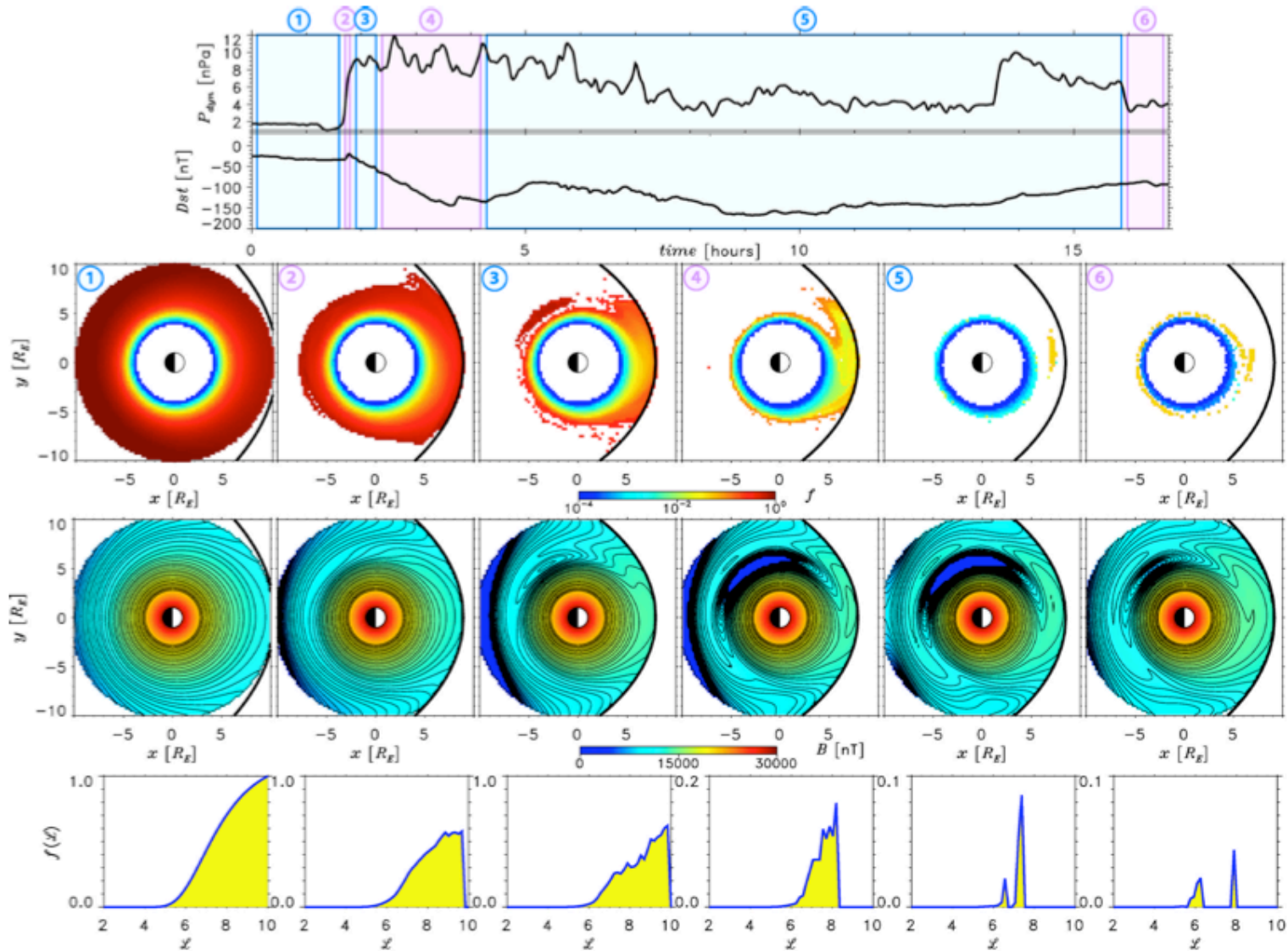
Interpolate ionospheric potential to RCM grid

Map open-closed field line boundary to RCM grid



Taken from De Zeeuw et al., 2004

## Recent Progress: Radiation Belt Model with Test-Particle Approach

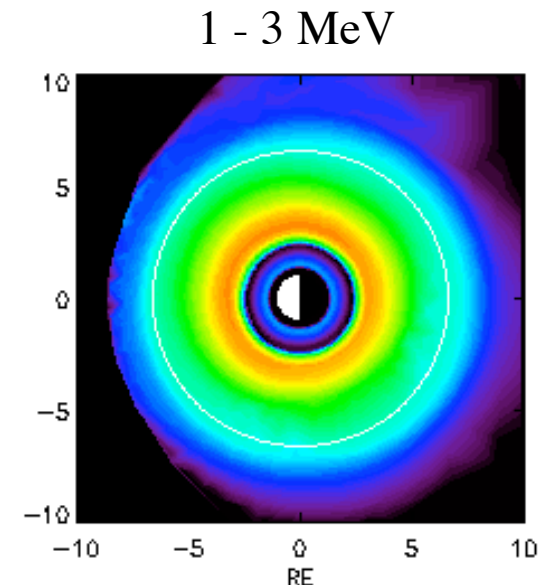
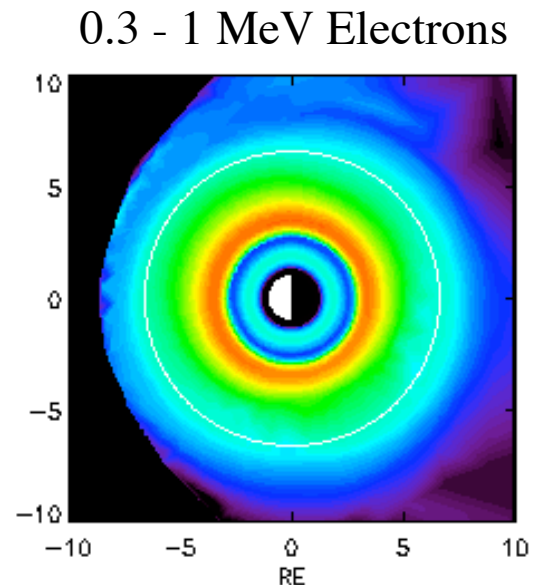
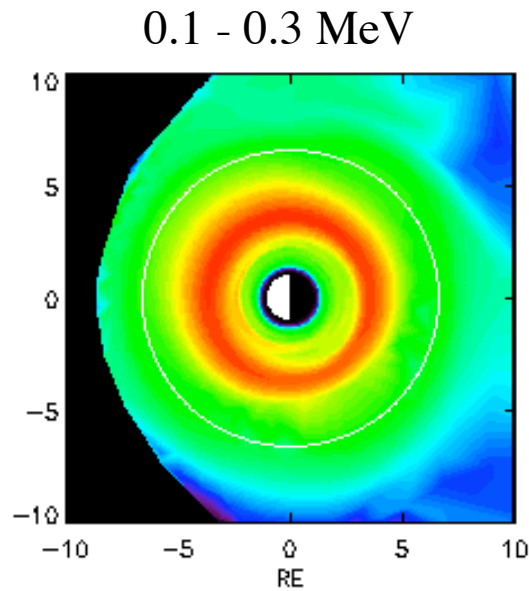


Taken from Ukhorskiy et al., 2006

## Recent Progress: Radiation Belt Model with Kinetic Approach

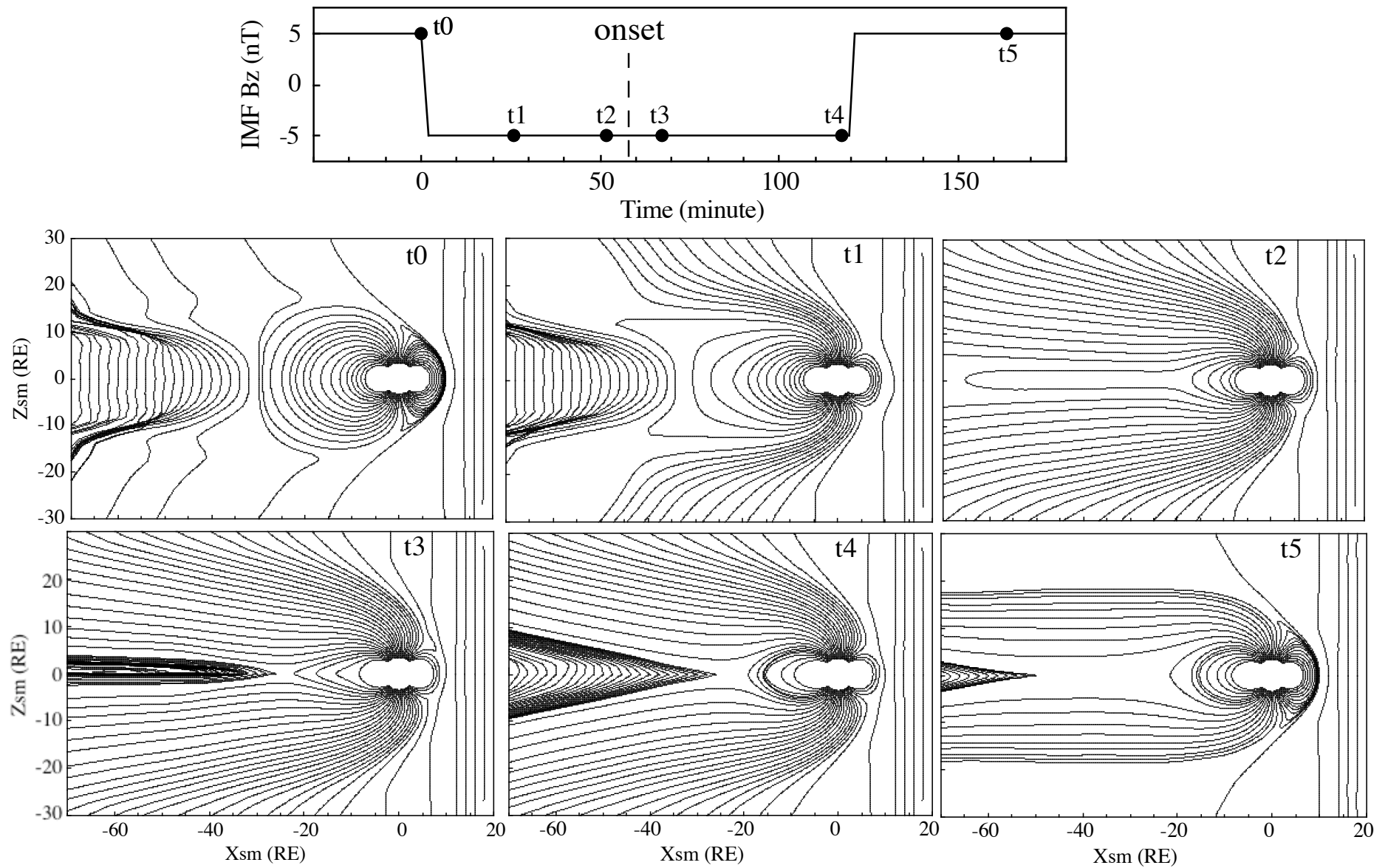
### The Radiation Belt Environment (RBE) Model

$$\frac{\partial f_s}{\partial t} + \langle \dot{\lambda}_i \rangle \frac{\partial f_s}{\partial \lambda_i} + \langle \dot{\phi}_i \rangle \frac{\partial f_s}{\partial \phi_i} = \frac{1}{\sqrt{M}} \frac{\partial}{\partial M} \left( \sqrt{M} D_{MM} \frac{\partial f_s}{\partial M} \right) + \frac{1}{T(y) \sin 2\alpha_o} \frac{\partial}{\partial \alpha_o} \left( T(y) \sin 2\alpha_o D_{\alpha_o \alpha_o} \frac{\partial f_s}{\partial \alpha_o} \right) - \left( \frac{f_s}{0.5 \tau_b} \right)_{\text{loss cone}}$$

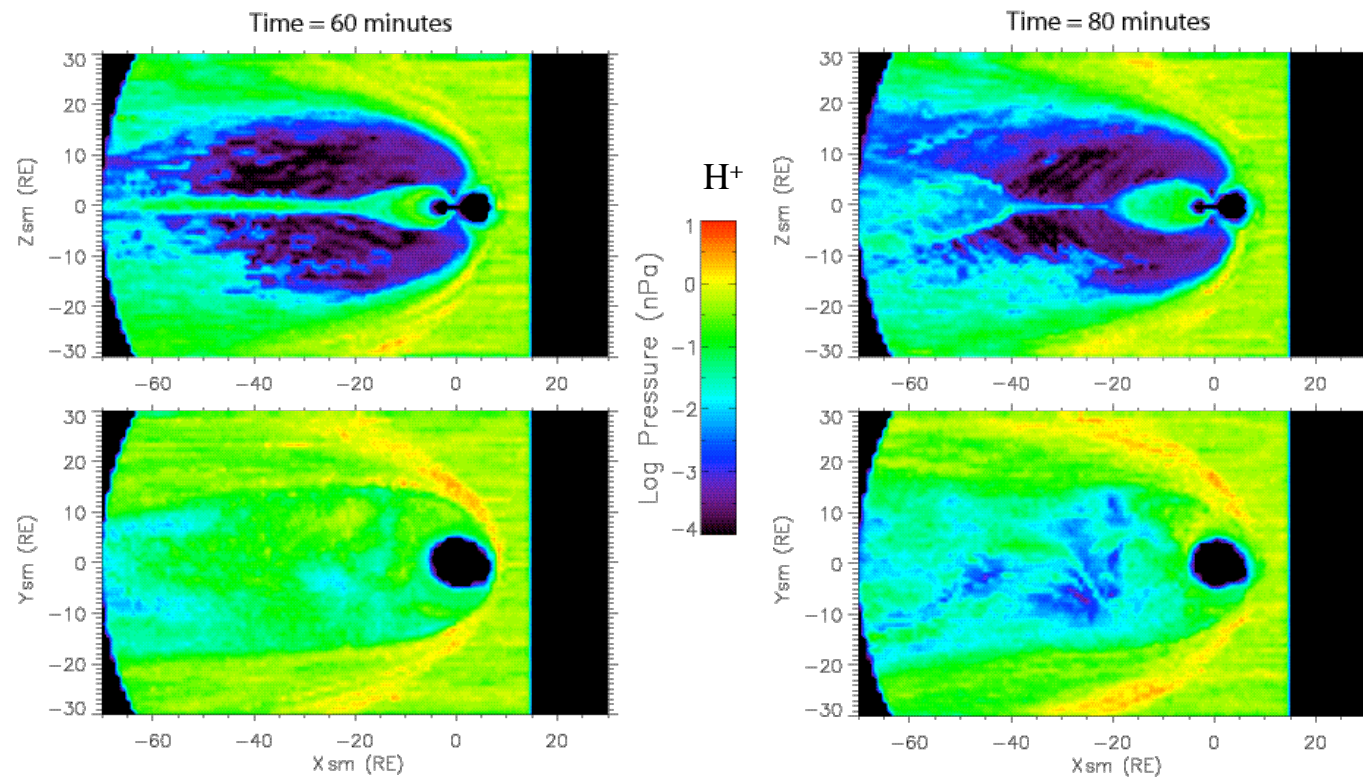




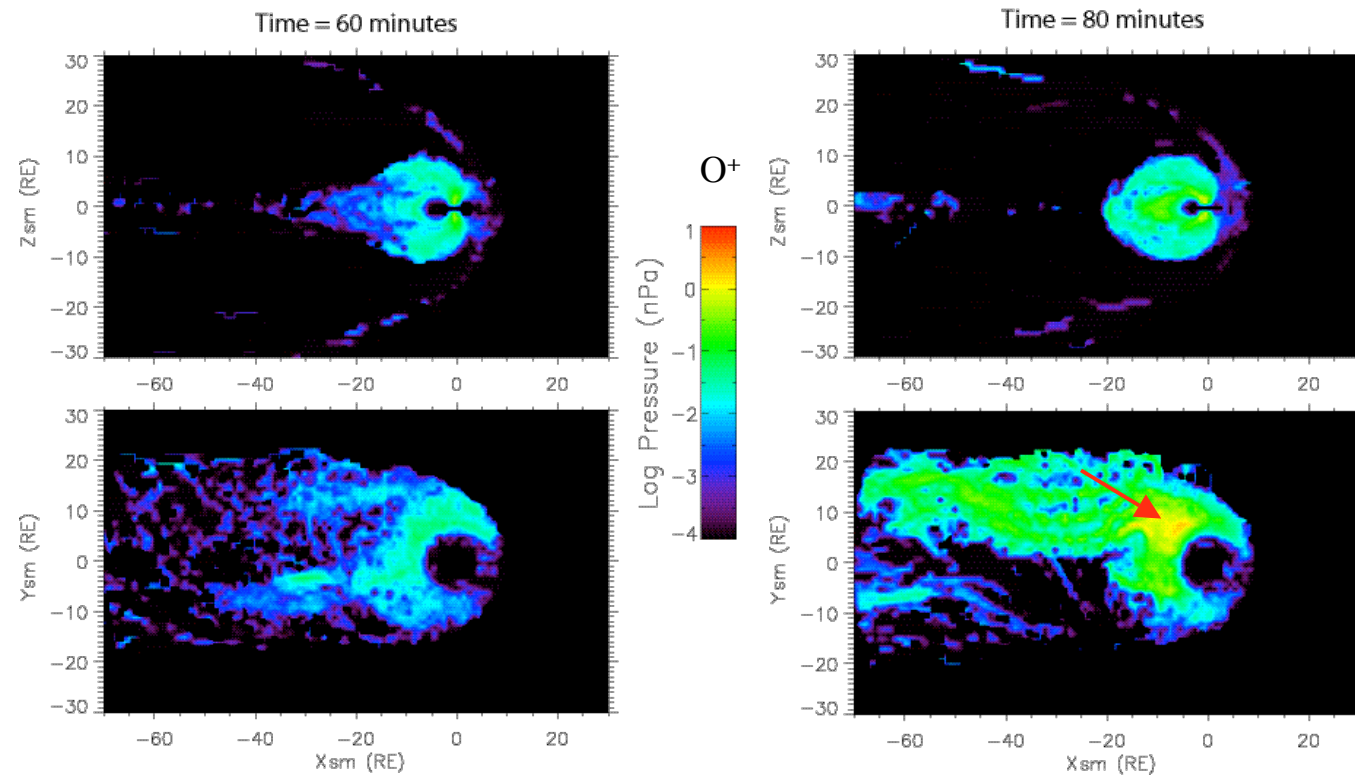
## Fok: Model Ion Injections During a LFM Substorm



## Fok: H<sup>+</sup> Ions Launched from the Solar Wind and Polar Wind



## Fok: O<sup>+</sup> Ions Launched from the Auroral Region (Auroral Wind)

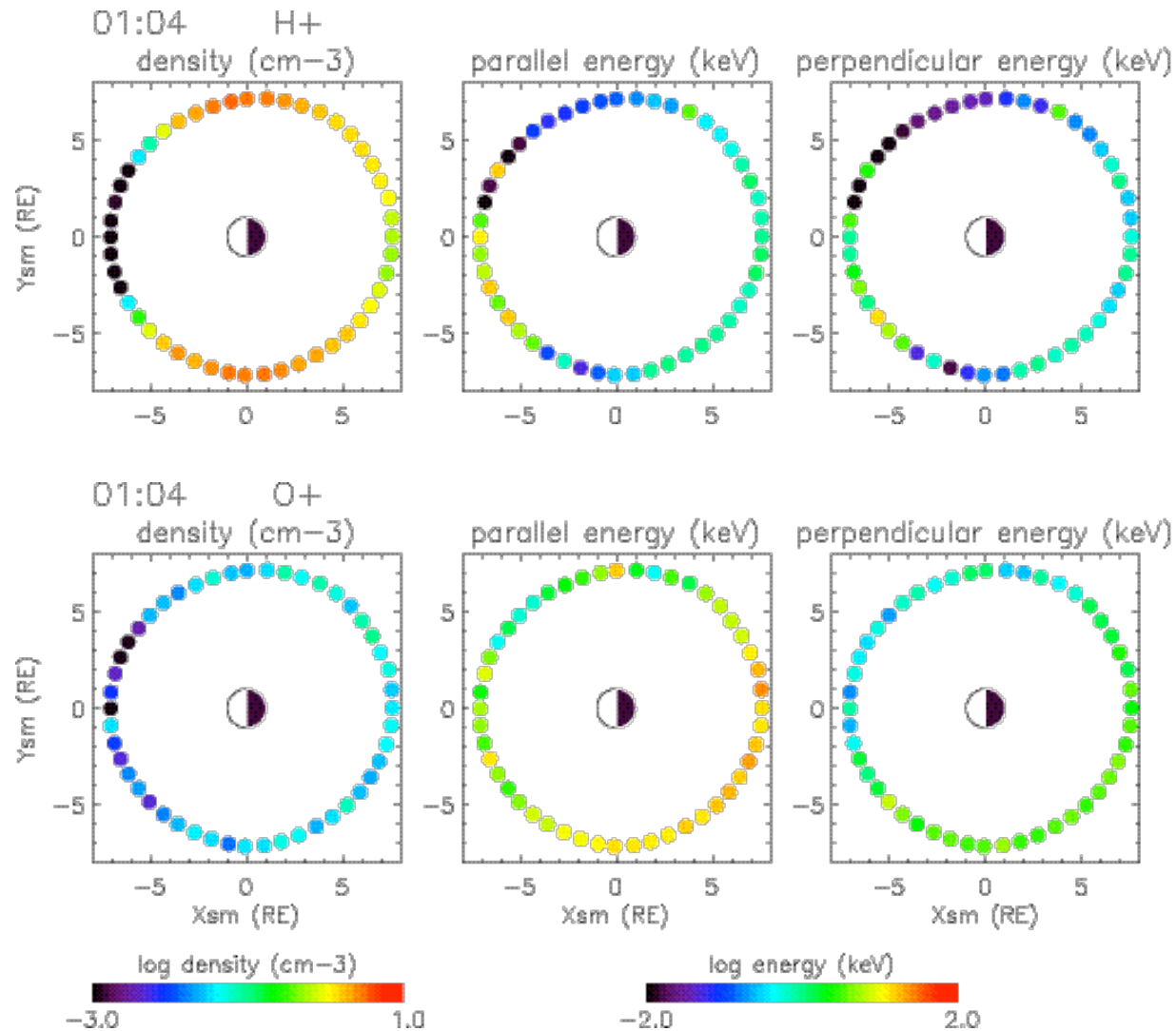


- We found the O<sup>+</sup> bursts seen during substorms are results of nonadiabatic energization of the preexisting O<sup>+</sup> in the plasma sheet, without the contribution from direct injection of ionospheric ions.



# Fok: Running the CRCM with LFM Fields

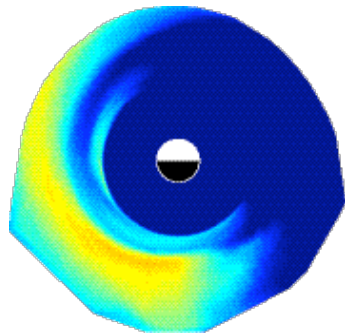
## Ion characteristics at the CRCM outer boundary



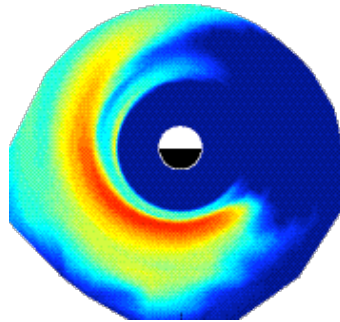
## Fok: CRCM Reproduces the O+ Enhancement During Substorm

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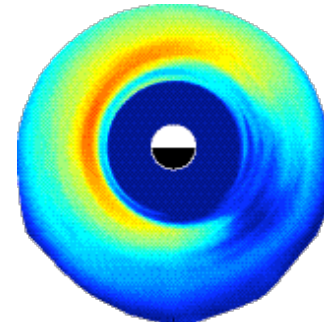
CRCM Simulated O+



$\Delta t = 44$  min.



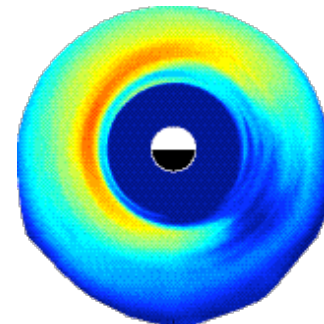
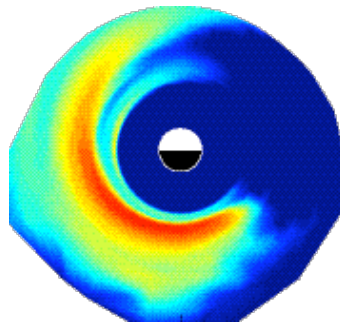
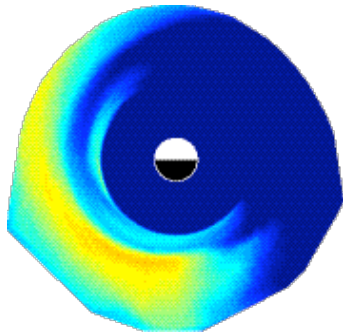
$\Delta t = 52$  min.



## Fok: CRCM Reproduces the O+ Enhancement During Substorm

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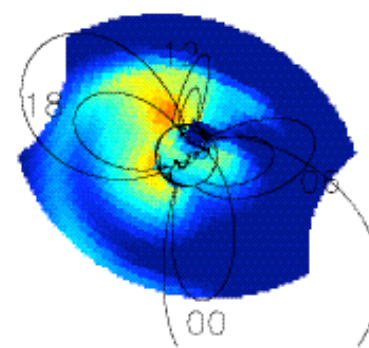
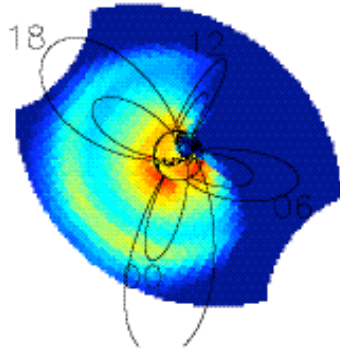
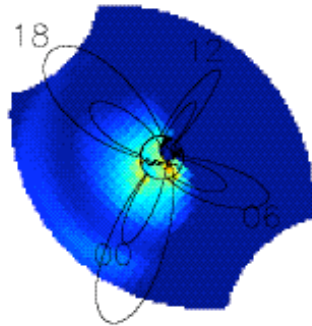
CRCM Simulated O+



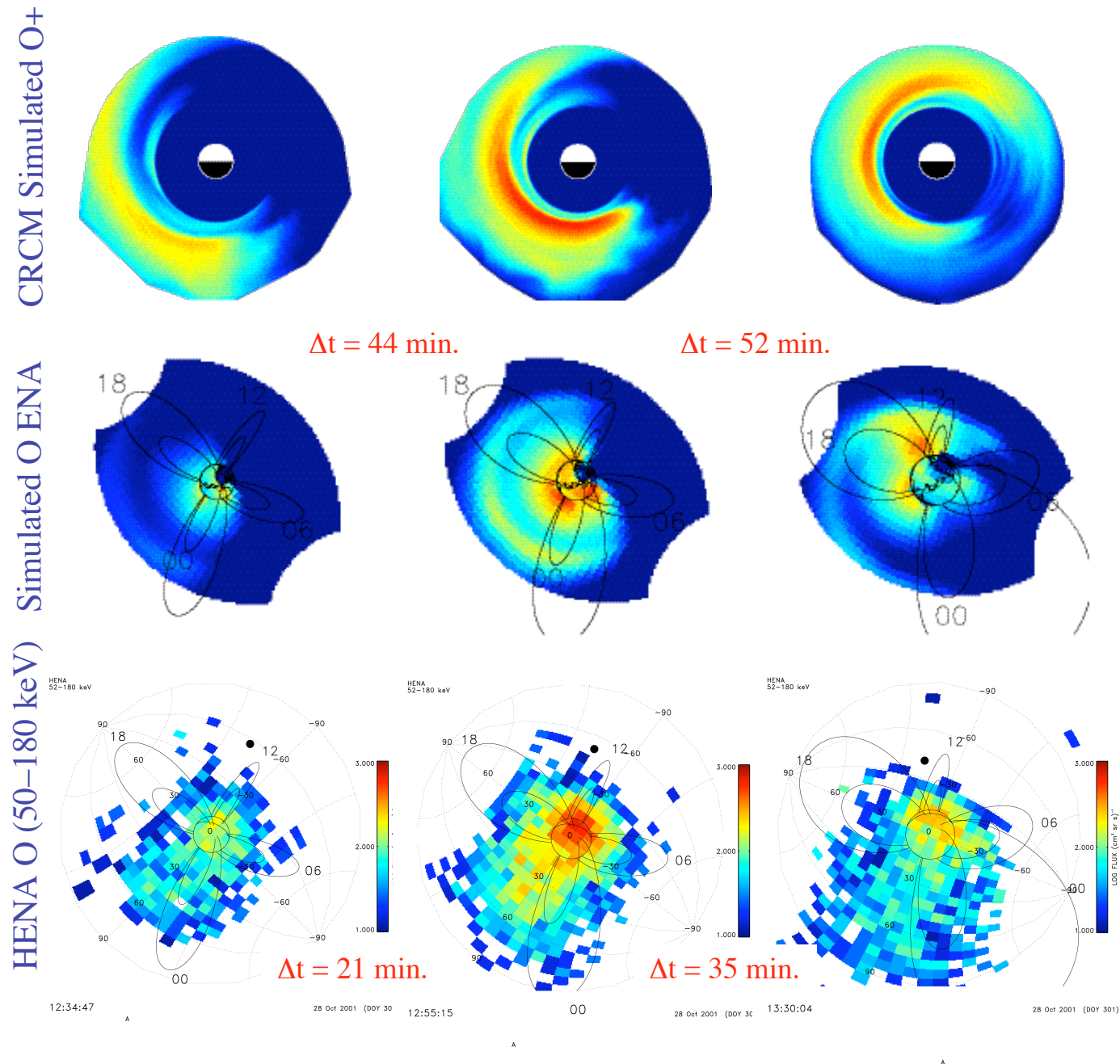
$\Delta t = 44$  min.

$\Delta t = 52$  min.

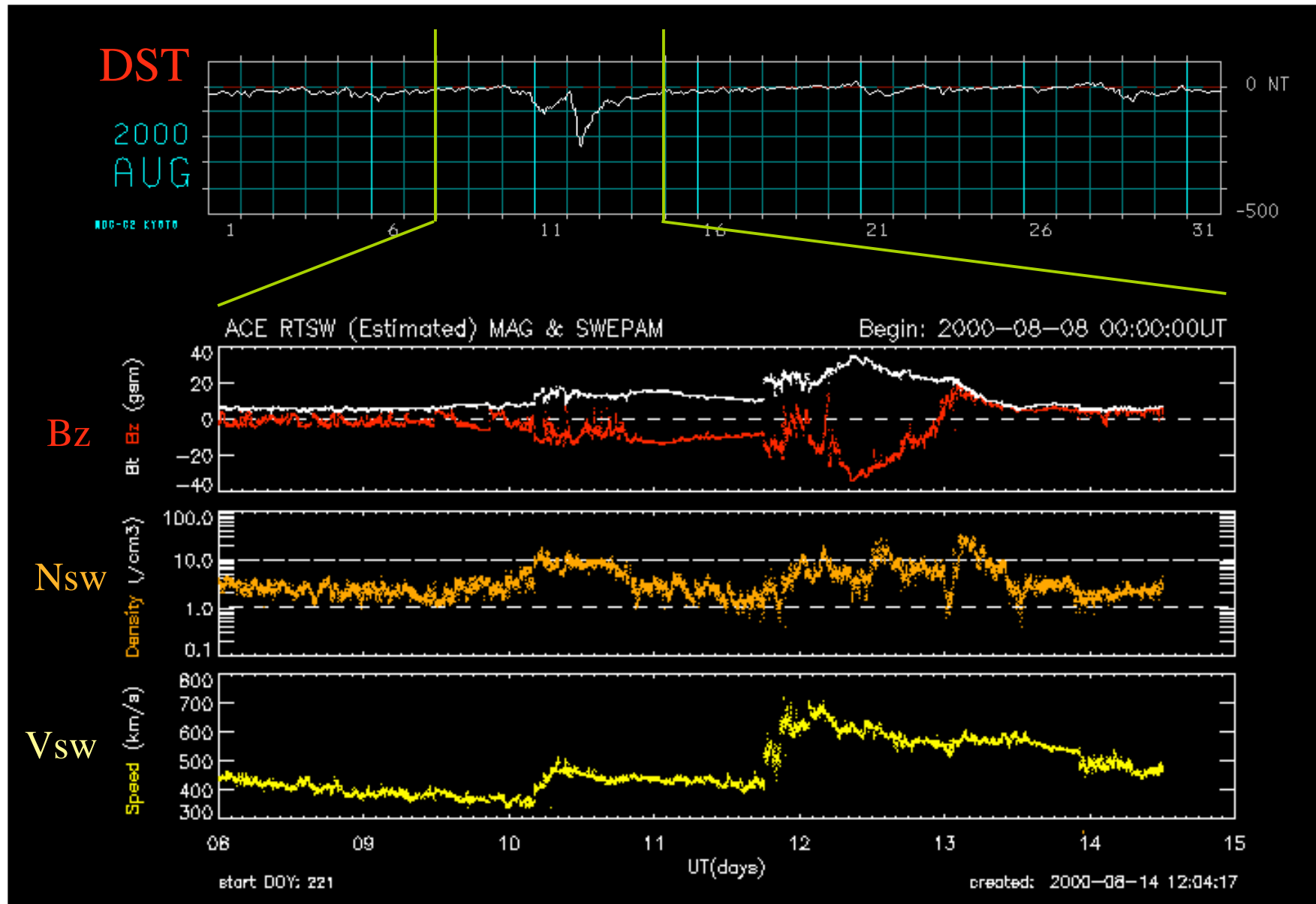
Simulated O ENA



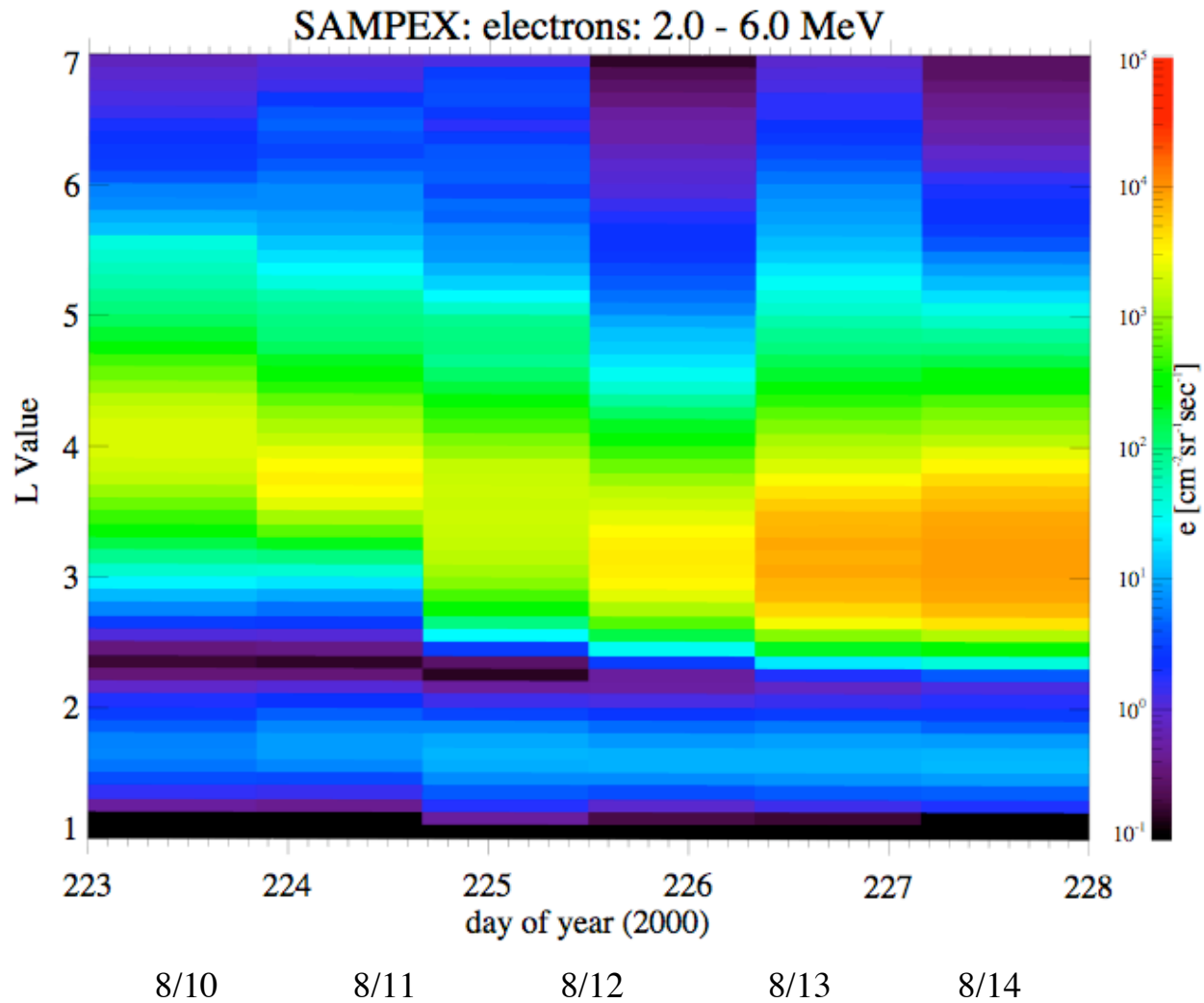
# Fok: CRCM Reproduces the O+ Enhancement During Substorm



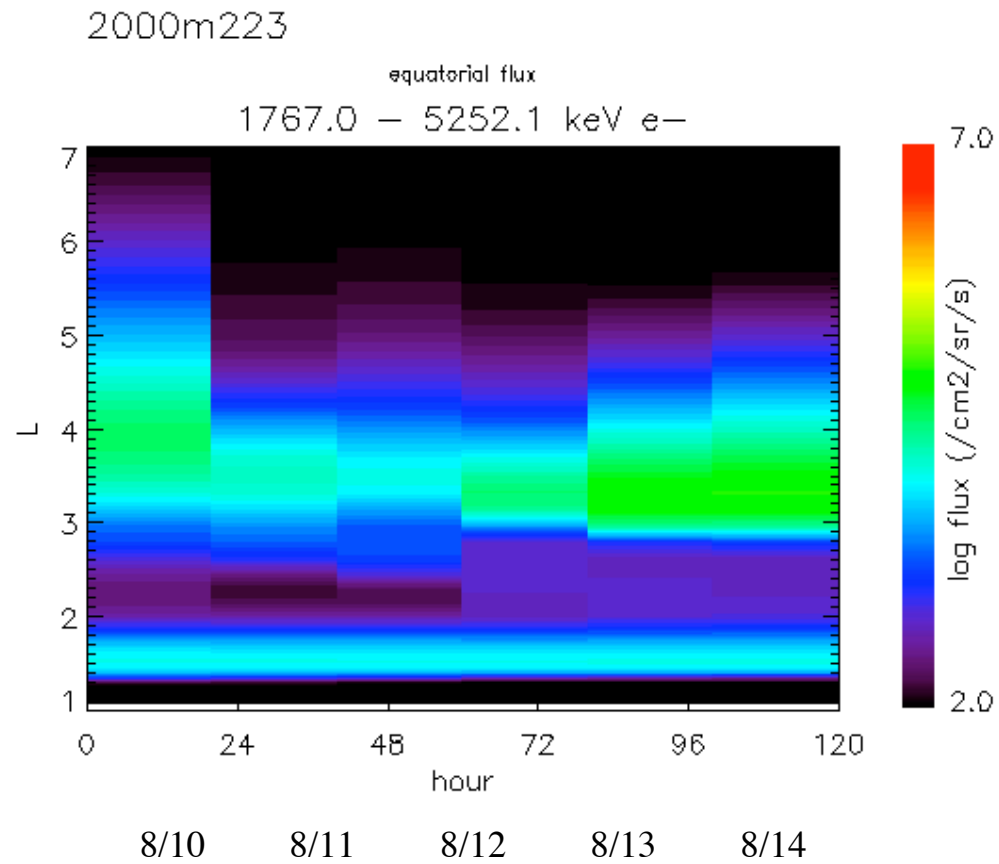
## Fok: RBE Simulation of the Great Magnetic Storm in August 2000



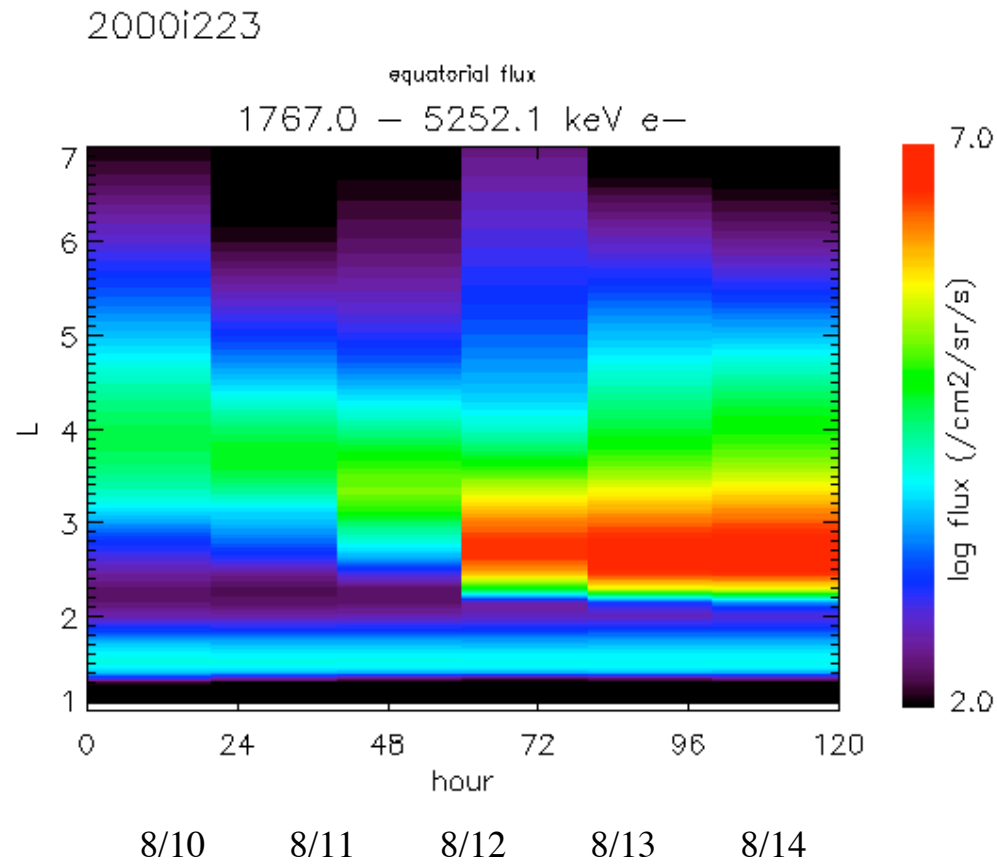
## Filling of the Slot Region During the August 2000 Storm



## Fok: RBE Simulation in Tsyganenko 96 Magnetic Field Model



## Fok: RBE Simulation in Tsyganenko 04 Magnetic Field Model

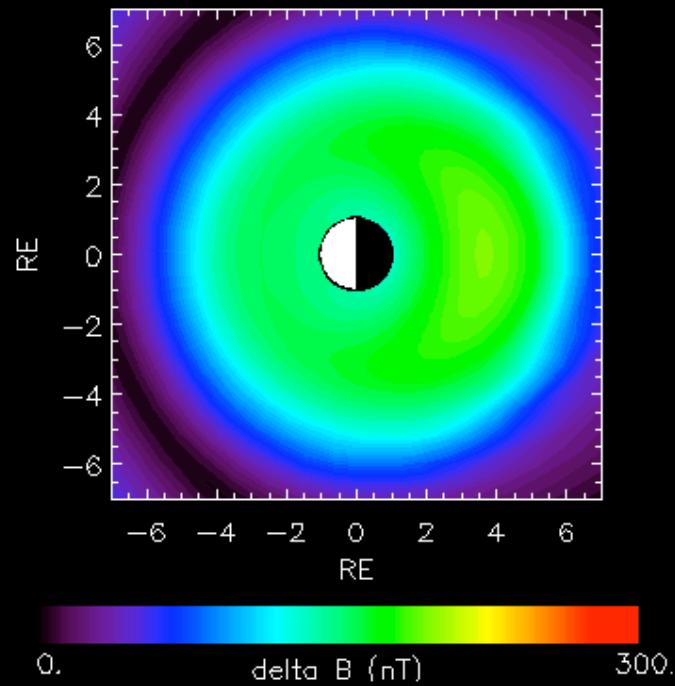




## Magnetic Field Distortion in T96 and T04

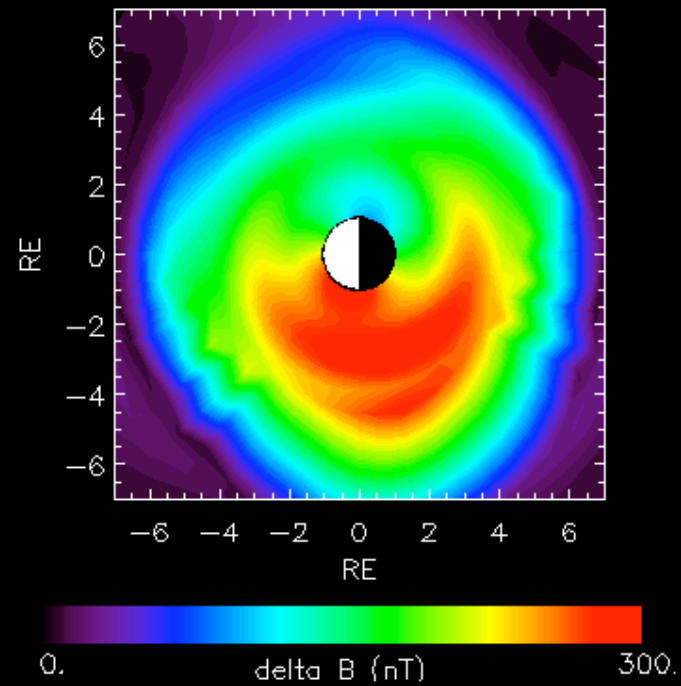
12 Aug 2000, 10:00 UT

T96



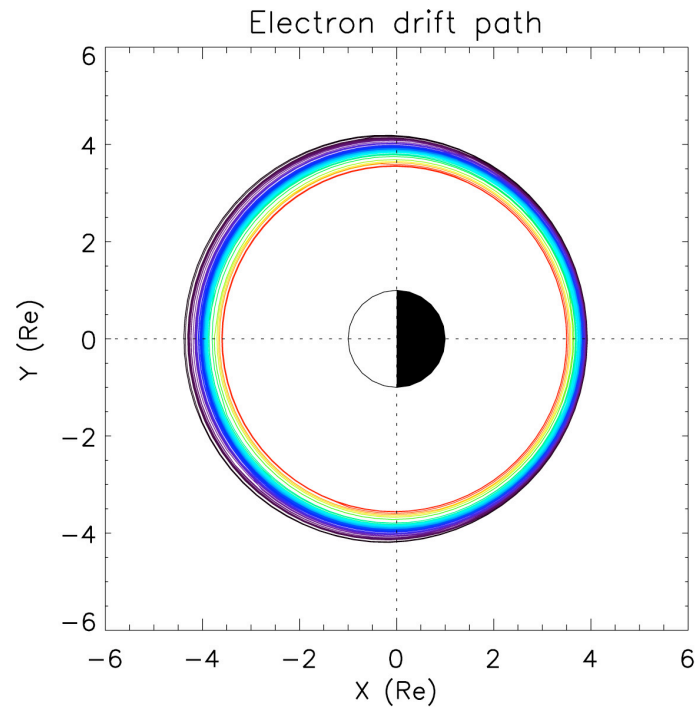
parmod(1:4): 3.0, -100, 10., -10.

T04



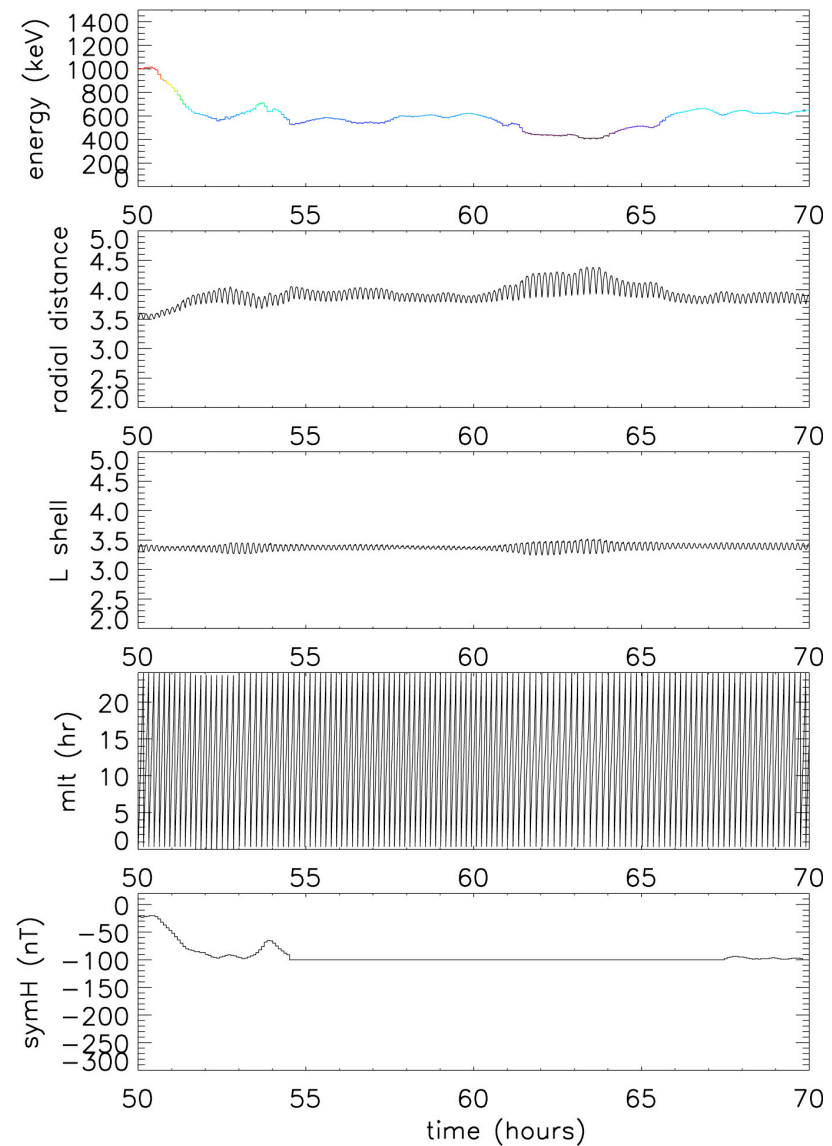
parmod(1:10): 3.0, -232, 22., -25.  
5.8, 3.6, 5.1,  
15.8, 6.7, 9.3

## Fok: MeV Electron Drifts in Tsyganenko 96 Magnetic Field

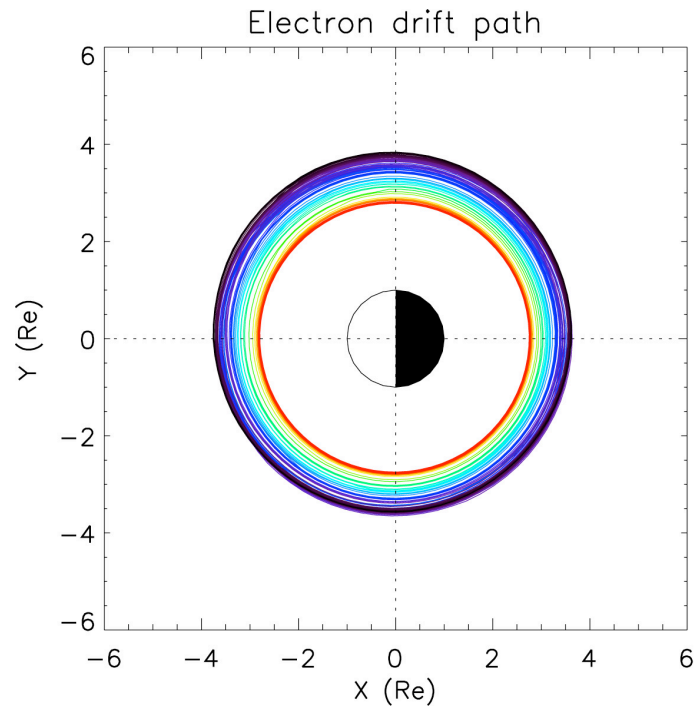


Start, Stop Parameters:  
Time (hour): 50.00, 70.00  
Energy (keV): 1000.00, 652.52  
Distance (Re): 3.50, 3.89  
L shell: 3.30, 3.42  
Magnetic local time: 0.00, 15.22

90° pitch-angle particle

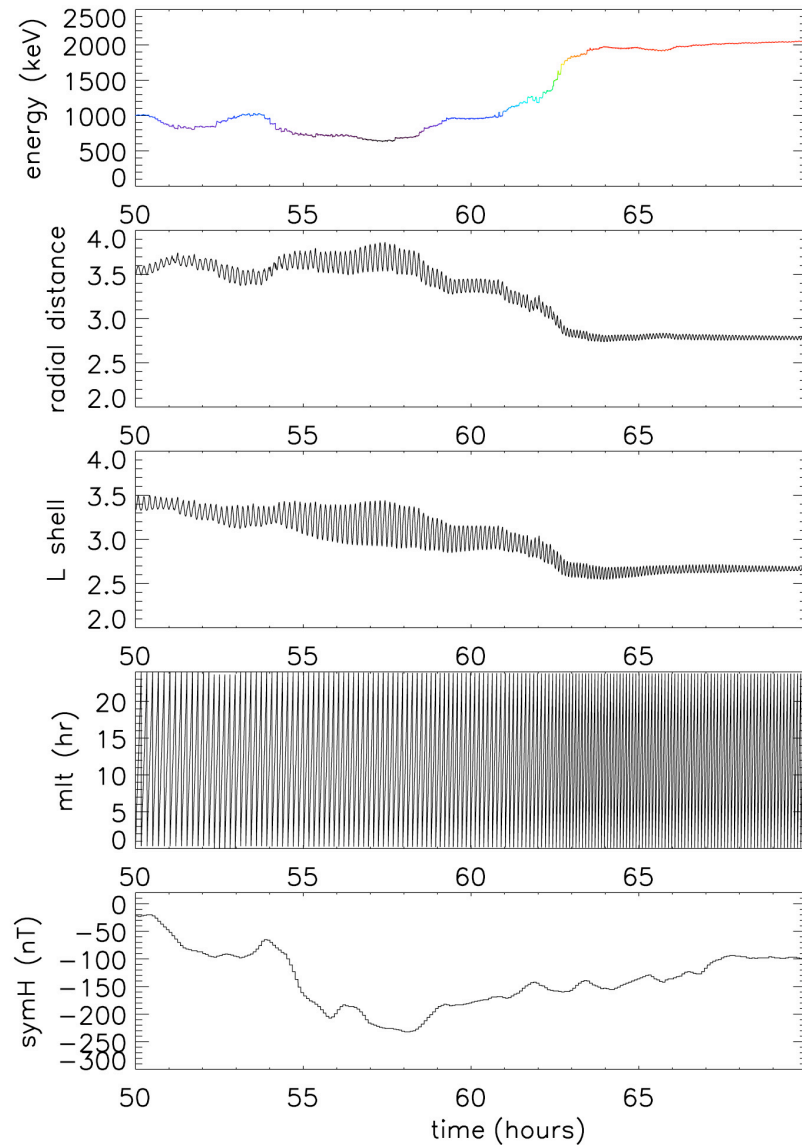


## Fok: MeV Electron Drifts in Tsyganenko 04 Magnetic Field



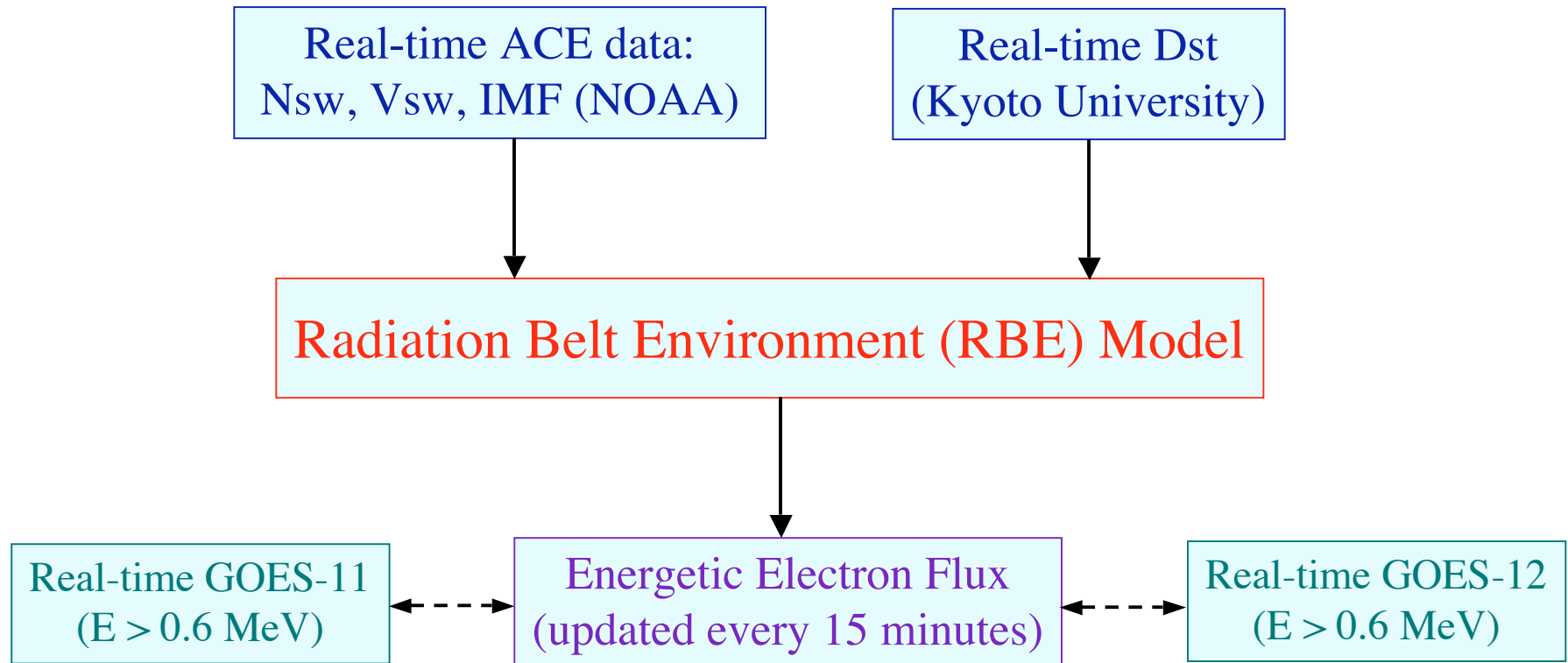
Start, Stop Parameters:  
Time (hour): 50.00, 70.00  
Energy (keV): 1000.00, 2049.71  
Distance (Re): 3.50, 2.78  
L shell: 3.33, 2.66  
Magnetic local time: 0.00, 17.39

90° pitch-angle particle

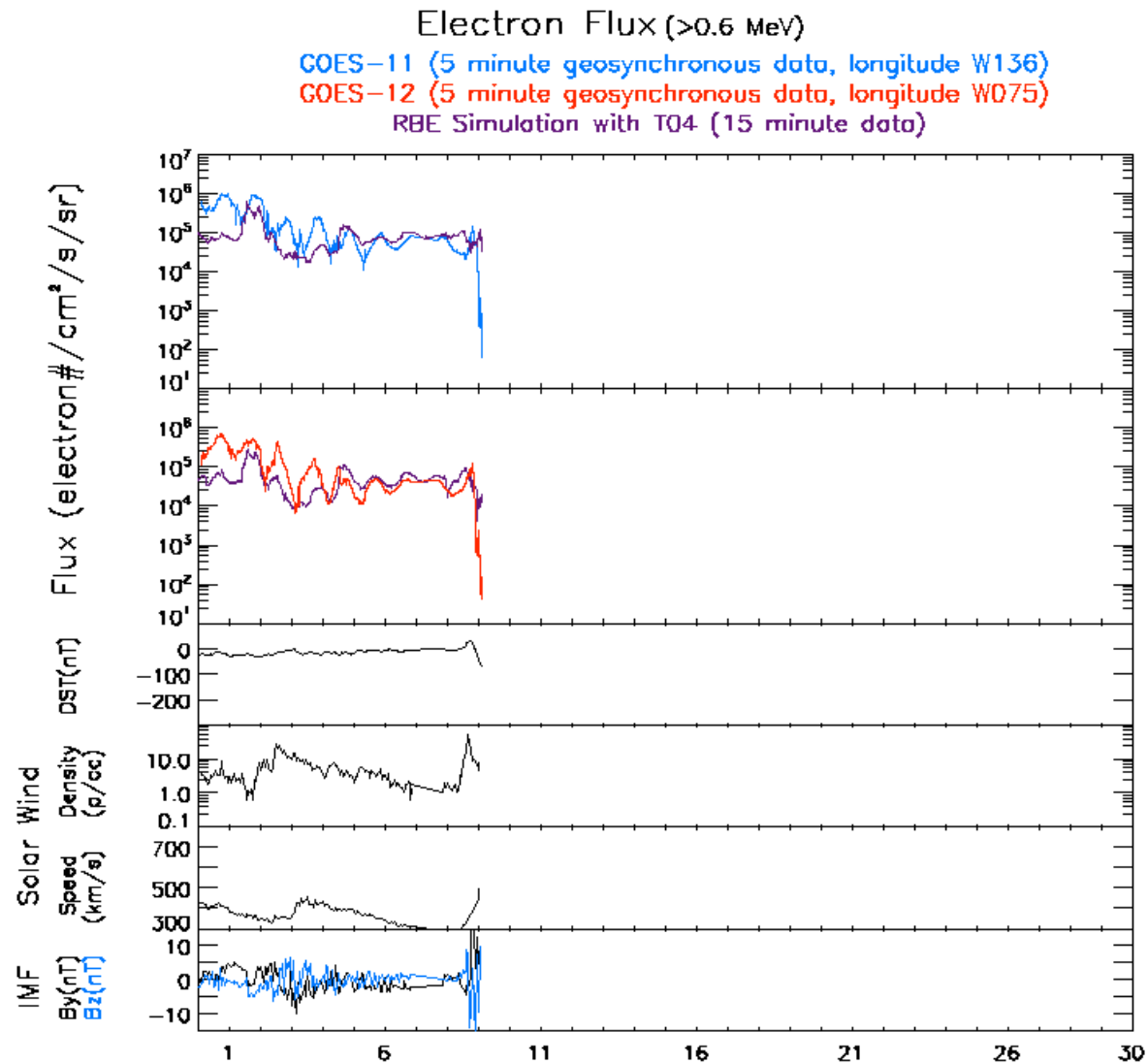


## Fok: The RBE Model Running in Real Time

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[http://mcf.gsfc.nasa.gov/RB\\_nowcast/](http://mcf.gsfc.nasa.gov/RB_nowcast/)



Fri Nov 10 02:48:39 2006

November 2006

## Future Challenges

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- ❖ A comprehensive model of the inner magnetosphere:
  - includes both ring current and radiation belt energies
  - self-consistent electric field
  - self-consistent magnetic field (force-balance approach)
  - considers all important processes, i.e., wave-particle interactions
- ❖ The model is fast enough that can be run in real time:
  - run on machines with multiple processors
- ❖ Connect the inner-magnetosphere model with a solar wind model
- ❖ Model validation through extensive data-model comparison